SPONGE FARMING IN THE MEDITERRANEAN SEA: NEW PERSPECTIVES

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Some Mediterranean species of *Spongia* and *Hippospongia* are characterised by a soft and absorbent skeleton and usually harvested for commercial purposes. Recently, the synergetic effect of a widespread epidemic, together with overfishing, has strongly reduced their density, leading local populations of these species to the brink of extinction. Recovery of populations takes a long time and even now, after several years, sponge density is still very low. A simple solution to this problem is sponge-farming. Sponges are sessile filter feeding organisms and through their pumping activity they are able to retain bacteria and suspended organic matter from the entire water-column in littoral marine environments. This ability provides the basis for an integrated aquaculture of sponges and fish in coastal areas: floating-cage fish farms release a lot of organic wastes that can be recycled as a rich source of food for surrounding intensive commercial sponge cultures. Moreover, the interest shown by chemists and pharmacologists in regard to natural products extracted from sponges creates new possibilities for sponge farming. ❒ *Porifera, aquaculture, organic pollution, overfishing, bath sponges, natural products, cicatrisation.*

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Commercial 'horny' or Keratose sponges have been harvested and utilised as bath sponges since ancient times. Phoenicians and Egyptians collected sponges stranded along the seashore, while the millenary history of sponge fishery takes root in the ancient Greek civilisation. Traditionally fishermen used a heavy stone as ballast to easily reach the sea bottom and gather sponges into a net basket. At the end of the last century this harvesting system was replaced by 'hard hat' diving-suits. The introduction of this device rapidly increased fishing effort, although many divers died from decompression sickness, and as a consequence many Governments banned this technique. Modern developments in hyperbaric medicine and diving equipment have since solved both legal and medical problems associated with commercial diving activities, but have created a new suite of problems for sponge fisheries.

In recent times sponge population density has continually decreased, both through overfishing and from the so-called sponge disease. Older professional divers relate the existence of an incredible abundance of commercial species during the 1930s, along the coasts of Cyprus, Crete and Sardinia, consisting of more than 200-300 specimens/100m^2. Prior to the sponge disease epidemic, unexploited commercial sponge banks contained sponge densities of about 100 specimens/100m^2, whereas at present, the mean density is often less than 50 specimens/100m^2 (Pronzato et al., 1996, 1999; Pronzato, 1999).

Sponge diseases do not occur frequently, but have been recorded in populations from both the Mediterranean and Caribbean Seas. Between 1985-1988 commercial sponges practically disappeared in many of these areas, especially in the eastern Mediterranean Basin, with consequent heavy economic losses. Sick sponges are easily recognisable through exposure of their internal skeleton. Sponge disease is caused by invasive pathogenic micro-organisms: first they destroy the sponge's external fibrous layer, then proceed rapidly into the sponge body, destroying living tissues. Fibres become fragile and flake off, losing their characteristic durability and

TABLE 1. Percentage of survival of monitored species farmed in Kalymnos and Paraggi. *Hippospongia communis*, *Petrosia ficiformis* and *Cacospongia mollior* are perfectly suited, while *Axinella damicornis* and *Ircinia variabilis* are unsuitable. Abbreviation: N=no. of transplanted fragments.

Species	N	Survival after 48 hours (%)	Survival after 2 months (%)
Kalymnos (Dodecanese, Greece)			
Spongia officinalis	75	69.4	69.4
Hippospongia communis	252	100	100
Paraggi (Ligurian Sea, Italy)			
Agelas oroides	46	45.8	44
Axinella damicornis	50	0	0
Cacospongia mollior	60	83.3	83.3
Ircinia variabilis	50	2	1
Petrosia ficiformis	40	100	98
Spongia officinalis	50	66	66
Spongia agaricina	49	42.8	40

softness (Gaino & Pronzato, 1989; Pronzato & Gaino, 1991; Gaino et al., 1992). There is undoubtedly a synergetic effect between over-fishing and sponge disease in reducing populations, given that overexploitation may lower the sponge's self-defence mechanisms, increasing the risk of environmental aggravation (Pronzato, 1999). Moreover, it is also known that types of pollution are responsible for decreasing biodiversity amongst Porifera (Pansini & Pronzato, 1975; Carballo et al., 1996).

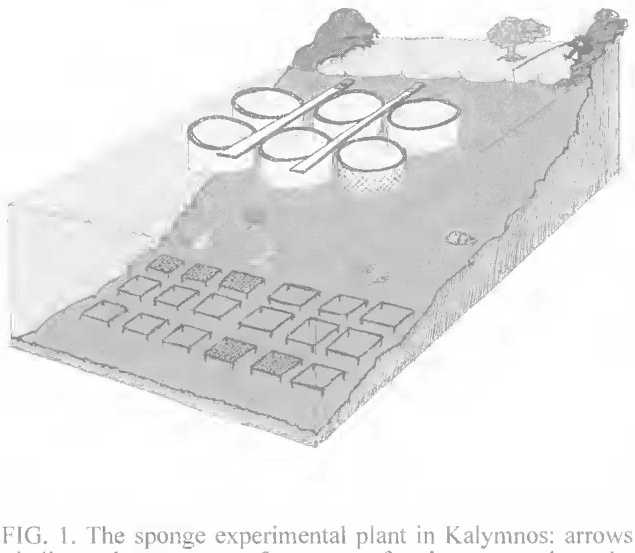

FIG. 1. The sponge experimental plant in Kalymnos: arrows indicate the structures for sponge farming, moored on the bottom.

Due to depletion of sponge populations from 1960-1990 many commercial producers have gone out of business, with exports from many Mediterranean countries diminishing substantially. The decrease in catch has produced a sharp increase in price for Mediterranean sponges, with the consequence that lower quality, cheaper Caribbean and Pacific stocks have invaded the market (Verdenal & Vacelet, 1990). Recovery of the sponge banks is a long term process (Rizzitello et al., 1997). Ten years after the onset of Mediterranean sponge disease, commercial sponges are still rare in many sites we examined during our experiments (this paper).

In the last few years chemical researchers have also shown an interest in sponge culture, owing to the presence of natural products useful in pharmacology. Metabolites extracted from Porifera are providing promising results in the prevention and treatment of tumours (De Flora et al., 1995), antiphlogistic compounds (De Rosa et al., 1995) and other properties (Uriz et al., 1991). Moreover, sponge extracts appear in catalogues of laboratory products at very high prices. Our goal is to satisfy the market request for these products without reducing natural populations.

This paper reports on the preliminary results from two different experiments in sponge farming. The first aimed to reconvert sponge fishery toward a more profitable and environmentally sustainable activity, located in Kalymnos Island (Dodecanese, Greece), during March 1998. The two target species were *Spongia officinalis* and *Hippospongia communis,* the most common commercial species in this area. The second experimental sponge culture was directed towards pharmacology, located in the W Mediterranean (Paraggi, Ligurian Sea), testing the survival of different non-commercial sponge species under farming conditions.

MATERIALS AND METHODS

The study site in Kalymnos (Dodecanese, Greece: 36°58'N, 27°02'E), was situated in the sheltered Bay of Vathi where there was a fish farming plant hosting 30 floating cages. During March 1998 four metallic

FIG. 2. The horizontal structures moored on the bottom with sponge fragments fixed onto lines.

horizontal structures were moored on a flat bottom 200-500m away from the floating fish cages at 15m depth (Figs 1-2). Specimens of *S. officinalis* var. *adriatica* and *H. communis* were cut into 4x4cm fragments and threaded onto a nylon line, separated by plastic tube spacers (7x0.6cm) (Figs 2, 3A,B). In total, 350 fragments were attached to lines. A team of operators monitored the plant of Kalymnos daily for the first week, and subsequently every ten days for the following two months.

Using the same method, the plant at Paraggi (Ligurian Sea, Italy: 44°18'N, 9°09'E), was situated on a flat bottom, at a depth of 25m. During May 1998 fifty fragments were obtained from each of the following species: *Agelas oroides*, *Axinella damicornis*, *Cacospongia mollior*, *Chondrosia reniformis*, *Ircinia variabilis*, *Petrosia ficiformis*, *S. agaricina* and *S. officinalis* var. *adriatica*. These were fixed onto horizontal structures using the methods described above. These species are the most common sponges living on the rocky cliffs of the Ligurian Sea.

During the first week of experiments samples from the cut surfaces were collected daily from both plants (Paraggi and Kalymnos), fixed in Glutaraldehyde 2.5% in ASW, dehydrated in a graded series of ethanol, critical-point dried using a Pabish CPD 750 drier coated with gold using a Balzers SCD 004 coater, and observed under a Philips EM 515 scanning electron microscope.

RESULTS AND DISCUSSION

Many experimental approaches have been applied to investigate the problem of producing a profitable sponge culture since the beginning of the century, and at present, some data are well-grounded (see Pronzato, 1999, for a review). From these data, on average, over two years sponges increase their volume by 100-200%.

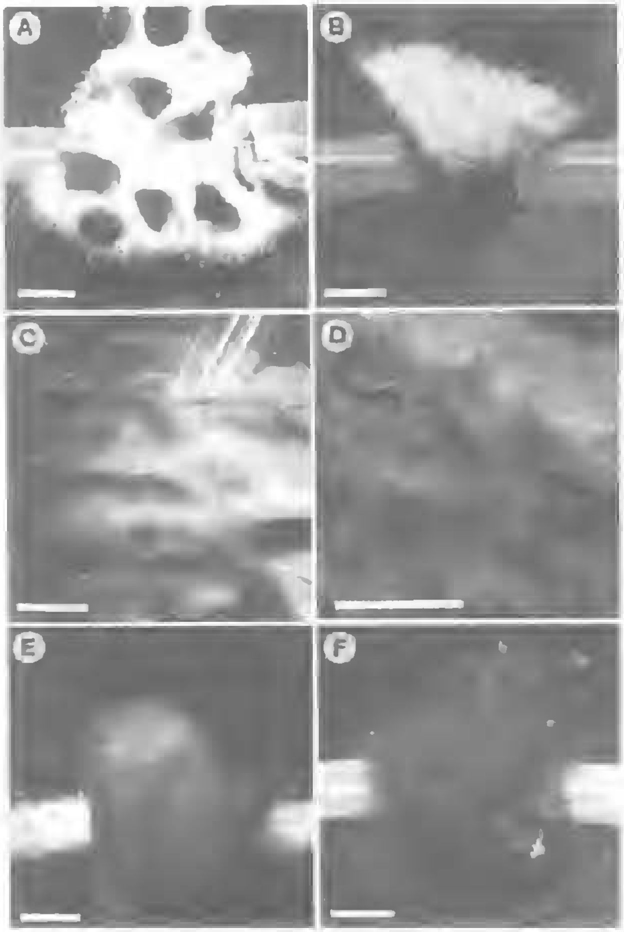

FIG. 3. A, Fragments of *Hippospongia communis*. B, *Spongia officinalis* just after transplantation: portions of the dark original external fibrous layer are maintained. C, Details of the thin cell layer in *H. communis* after 24hrs recovery. D, Thin cell layer recovering in *S. officinalis*. E, *Spongia officinalis* three weeks after transplantation: the characteristic dark pigmentation and the rounded shape have been restored. F, A dead specimen of *S. officinalis*. Death occurs mainly after the first 48hrs of transplantation. (Scale bars=1cm).

Generally, smallest fragments show the highest growth rates (Verdenal & Vacelet, 1985).

KALYMNOS PLANT. Mean mortality, less than 20%, was limited to the first 48hrs after transplantation, and *H. communis* seemed to be more resistant than *S. officinalis*. In fact, *S. officinalis* showed a survival rate of 69.4% whereas *H. communis* gave excellent results with a survival of 100% (Table 1). Mortality may be due to high sedimentation rates which favours bacterial proliferation: only naked skeletons of dead fragments remained on the ropes (Fig. 3F).

The regenerative process starts immediately after transplantation. Within 2-3 days sponges rebuild their external protective layer; after 24hrs a thin transparent cell layer covers the cut surfaces (Fig. 3C,D). After one week the characteristic dark external pigmentation of the sponge was restored. After one month sponge fragments assumed a rounded shape, with the external fibrous layer and the aquiferous system of the cut surfaces completely reorganised (Fig. 3E).

Among all the phyla of filter feeders, sponges play a remarkable role in the auto-epurative processes of the sea (Sarà, 1973). In accordance with modern integrated aquaculture systems, the association of sponge culture with floating cage fish farms have the potential to reduce environmental impact on coastal areas due to pollution produced by intensive fish farming (Manconi et al., 1998; Pronzato et al., 1998). The major impact occurs on the sea bed, under floating cages, where a rain of particles falls on benthic organisms causing rapid eutrophication (i.e. decrease in dissolved oxygen and increase in nutrient levels) (Wu, 1995). Food wastes and faecal pellets released by captive fish are rapidly colonised and degraded by bacteria (Honjo & Roman, 1977). Filtering activity of sponges has the potential to contribute to reduce this pollution within the precinct of fish farms. Sponges can retain about 80% of organic particulate material suspended in water, and about 70% of bacteria (Reiswig, 1971, 1975), with sponges filtering the entire water column in a single day (Reiswig, 1974). This integrated aquaculture provides a double bonus: purified water and commercial bath sponges.

Following our first attempt the Municipality of Kalymnos is presently planning to farm many thousands of sponges within the boundaries of floating fish cages along the island's coast.

PARAGGI PLANT. *Petrosia ficiformis* was the most productive species at this site. The cut surface produced a new pinacoderm within 4-5 days, and survival of fragments was close to 100% (Table 1).

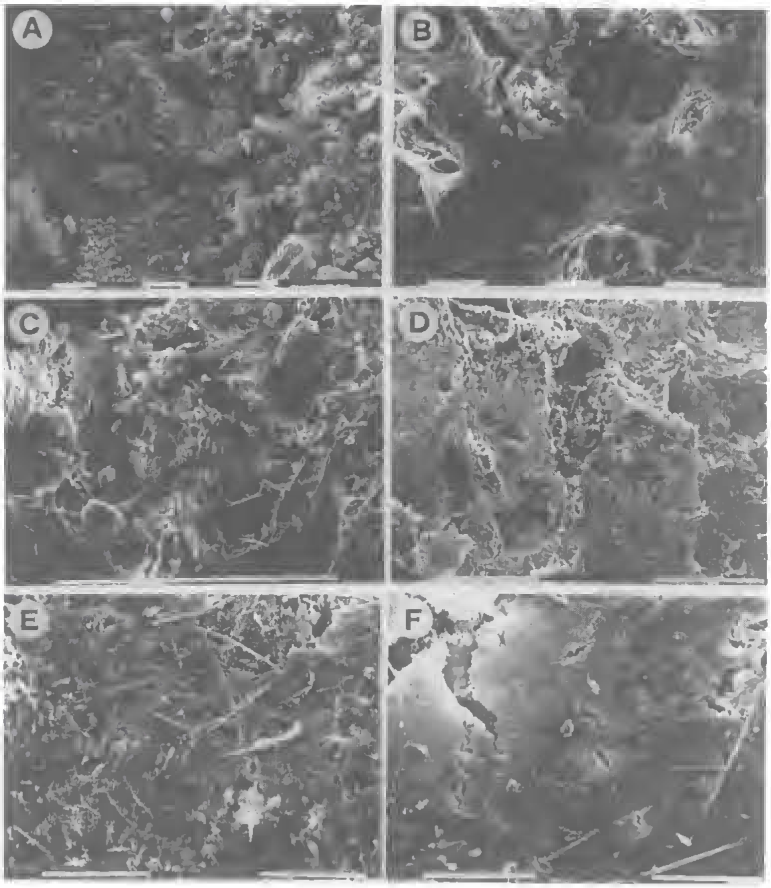

FIG. 4. The cicatrisating process of some investigated species. A, The cut surface on the day of transplantation in *Agelas oroides*. B, Cut surface of *Agelas oroides* after three days when the exopinacoderm is completely restored. C, Cut surface of *Axinella damicornis* after the first day. D, Cut surface of *Axinella damicornis* after the third day, where the external layer has not yet rebuilt. E, Cut surface of *Petrosia ficiformis* immediately after cutting. F, Cut surface of *Petrosia ficiformis* after three days, where the external cell layer is perfectly reconstructed. (Scale bars: A, D, E, F=100μm; B=10μm; C=1mm).

Axinella damicornis and *I. variabilis* showed a high mortality rate, probably due to damage incurred during the cutting process. In fact, *A. damicornis* is very fragile and must be handled with care, whereas *Ircinia* is so compact that it is difficult to cut without squeezing and potentially damaging tissues (Table 1).

Of all species tested, *C. reniformis* was completely unsuitable for our experimental conditions. The collagen matrix cut itself on the thread and in 1-2 days the sponge 'dripped' down from the thread. This behaviour, reminescent of the variable structure of Echinoderms (Candia Carnevali et al., 1990), is very interesting and the subject of a recent study (Bavestrello et al., 1998).

Recovery of the exposed choanosome starts from the borders of the cut and increases concentrically. The reconstruction process differs between species, depending on whether the external layer is a real pinacoderm, or, as for bath sponges (*Spongia* and *Hippospongia*), it is a fibrous layer without cells. Our experience shows that in *A. oroides* (Fig. 4A,B) and *P. ficiformis* (Fig. 4E,F) the restoration of the exopinacoderm is complete in 2-3 days, whereas in *A. damicornis* (Fig. 4C,D) this process does not occur at all.

Percentage survival rates of *S. officinalis* and *C. mollior* were satisfactory (about 60-80% over two months), and data on *S. officinalis* were concordant between the Kalymnos and Paraggi plants (Table 1). It is important to underline that environmental conditions, the state of health of the mother sponge, and techniques used in transplantation all influence survival and growth rate of farmed specimens, as also noted by Verdenal & Vacelet (1990). For instance, in their Marseilles farm, Verdenal & Vacelet (1990) found that *S. agaricina* showed a survival of 100% whereas we observed a mortality rate of about 60%.

Commercial bath sponges show the lowest mortality rate, probably due to the possession of a fibrous layer in which the recovery process is different from other species. Spherical cells, with long pseudopodia, travel along the cut edges producing collagen fibrils and completing the cicatrisation process after only a few days (Fig. 5).

The rapidity of reconstitution of the new external layer on cut portions of sponges varies

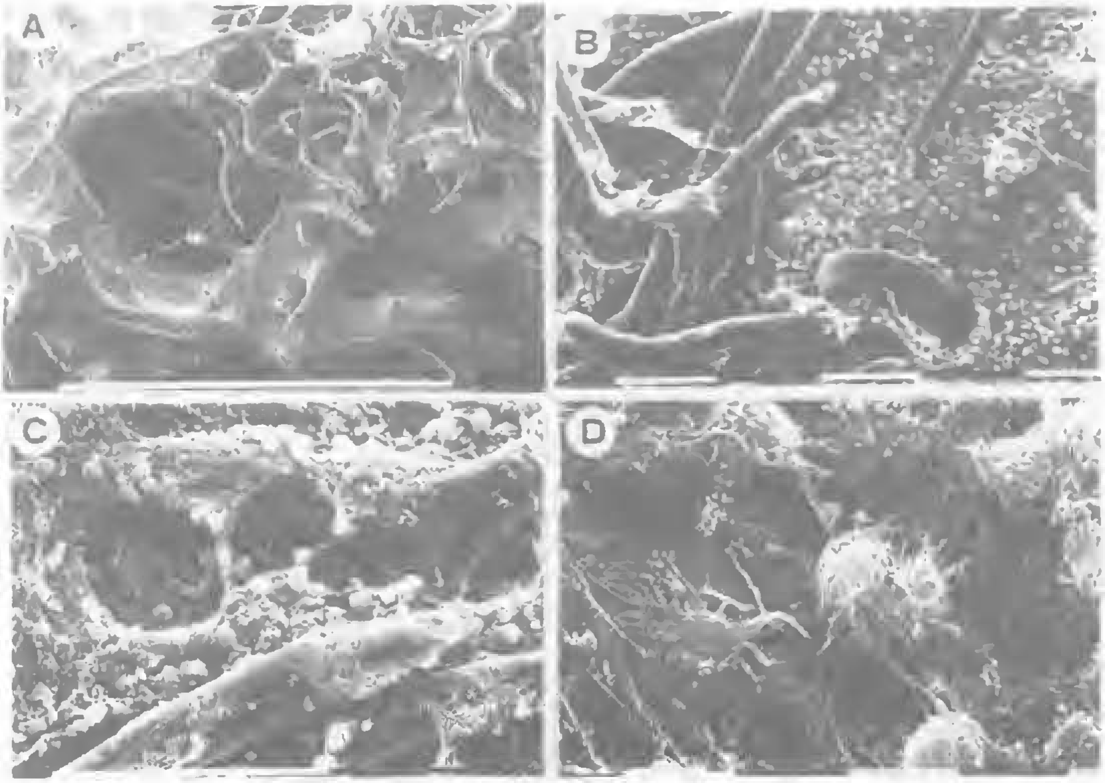

FIG. 5. A, The regenerative process of *Spongia agaricina* shows recovery of a new fibrous layer on exposed spongin fibers. B, Many globous mobile cells occur on the sponge surface. C, Elongated pseudopodia actively produce the collagen deposited on sponge fibers. D, After a few days the superficial fibrous layer is more-or-less completely restored. (Scale bars: A=1mm; B, C=100μm; D=10μm).

between species (e.g. 2-3 days in *A. oroides* and *P. ficiformis*; to about 10 days in *C. mollior*).

CONCLUSIONS

Commercial bath sponges have practically disappeared from the E Mediterranean Sea, owing to both overfishing and sponge disease. Sponge aquaculture has the potential to decrease fishing pressure, thus facilitating the natural repopulation of these affected areas.

Pharmacological research on marine natural products extracted from sponges are providing promising results, opening new perspectives in the exploitation of new species of Porifera. However, there are virtually no data on the densities of wild sponge banks for most species, and the risk of overfishing of potentially commercially valuable species could become real. An evaluation of the adaptability of the most common Mediterranean species to farming conditions could provide a valuable resource to any future exploitation of these species for pharmacological or other products.

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